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Star gooseberry (*Phyllanthus acidus*): An underutilized fruit with promising nutraceutical applications

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Abstract
Phyllanthus acidus, commonly known as star gooseberry, is a fruit bearing plant of notable nutritional and medicinal value. This review highlights the current production scenario, nutritional composition, and diverse health benefits of *P. acidus*, drawing from both traditional uses and modern scientific studies. The fruit is cultivated in various tropical regions and is recognized for its rich content of vitamin C, dietary fiber, and phytochemicals including phenolic compounds, flavonoids, and tannins. It exhibits significant pharmacological properties such as antioxidant, anti-inflammatory, antidiabetic, and antimicrobial activities. These bioactivities are attributed to its bioactive constituents like quercetin, gallic acid, kaempferol, and other polyphenols. The review underscores the therapeutic potential of *P. acidus* in managing oxidative stress-related disorders, metabolic diseases, and microbial infections, thereby supporting its use in functional foods, nutraceuticals, and traditional medicine. Further research and value addition strategies may enhance its utilization and economic importance.

Keywords: *Phyllanthus acidus*, Star gooseberry, Nutritional composition, Antioxidant activity, Anti-inflammatory, Antidiabetic, Antimicrobial, Traditional medicine.

Introduction
Star gooseberry (*Phyllanthus acidus*), a member of the Phyllanthaceae family, is an ancient tropical fruit native to Madagascar and now widely distributed across Asia and tropical regions worldwide. Despite its traditional significance and diverse local names such as Tahitian gooseberry, country gooseberry, and West Indian gooseberry this fruit remains largely underutilized and undervalued in commercial agriculture.

Typically cultivated in kitchen gardens and rural landscapes, *P. acidus* produces small, oblate, pale-yellow fruits that are highly perishable and prone to post-harvest losses. As a result, its commercial potential remains untapped in comparison to other Indian fruits like amla. However, the fruit possesses notable nutritional qualities, being rich in carbohydrates, ascorbic acid, calcium, potassium, and essential vitamins (Kavitha and Padmini, 2017) [21]. These attributes make it a promising candidate for both dietary and therapeutic applications.

Traditionally used in folk medicine systems such as Ayurveda and Asian medicinal practices, *Phyllanthus acidus* has been utilized to manage conditions including respiratory disorders, digestive issues, and inflammation (Tan *et al.*, 2020; Padmini and Kavitha, 2021) [21]. Scientific investigations now support many of these traditional claims, revealing the presence of various bioactive compounds like polyphenols and flavonoids, which contribute to its antioxidant, anti-inflammatory, antidiabetic, and antimicrobial activities.

Given the increasing demand for functional foods and natural remedies, *P. acidus* offers immense potential for value addition and health-focused product development. Its nutritional richness, coupled with medicinal benefits, underscores the need for greater attention toward its cultivation, processing, and utilization. This review aims to compile and present current knowledge on the production scenario, nutritional composition, and health-promoting properties of *Phyllanthus acidus*, thereby highlighting its significance as a functional food and promoting its use in sustainable food systems.

Production Scenario and Botanical Description of Star Gooseberry (*Phyllanthus acidus*)
Phyllanthus acidus, commonly known as star gooseberry, is a tropical species valued for both ornamental and practical purposes. Its aesthetically pleasing foliage makes it a popular choice in gardens. Belonging to the family Phyllanthaceae, it is part of the largest genus *Phyllanthus*, which includes approximately 1,270 species classified under 11 subgenera based on morphological and ecological traits namely *Isocladus*, *Kirganelia*, *Cicca*, *Emblica*, *Conani*, *Gomphidium*, *Phyllanthodendron*, *Xylophylla*, *Botryanthus*, *Ericocus*, and *Phyllanthus* (Rout *et al.*, 2010 [36]; Kathriarachchi *et al.*, 2006) [20]. The species is believed to have originated in Madagascar and subsequently spread to the East Indies. It is widely cultivated in regions such as Indonesia, South Vietnam, Laos, northern Malaya, and home gardens across India. It is also found in Guam, Hawaii, and other Pacific Islands, where its sour fruit is especially enjoyed by children (Morton *et al.*, 1987) [28].

Known by various vernacular names, *P. acidus* is called Cherme in Malaysia, Ceremai in Indonesia, and by numerous regional names in India including *Chalmeri*, *Harpharoi*, *Nellikai*, *Harfi*, *Arunellikai*, *Abazhanga*, *Nellipuli*, *Usiri*, *Khatamada*, *Arinelli*, *Bimbool*, *Arinellika*, *Kiru Nerle*, and *Mara Nelli*. It is referred to as *Arboroi* in Bangladesh, *Harbori* in Vietnam, *Chum Ruot* in Thailand, *Mayon* in the Philippines, *Karamay* in the USA, and *Tahitian gooseberry* in Jamaica (Tan *et al.*, 2020).

In southern India, fruiting generally occurs twice annually once between April and May and again from August to September. In contrast, other regions experience a fruiting season from November to January, with occasional off-season fruiting. Notably, in the Kodur region of South India, the species can yield fruit year-round, with a peak in January (Rymbai *et al.*, 2015) [37].

The plant prefers warm temperatures (65-70°F) and thrives in well-drained, fertile soils with ample sunlight. It is propagated through seeds, cuttings, budding, or air layering. Seeds take 4-6 weeks to germinate when planted at 0.5-1 inch depth under moist and humid conditions. Monsoon onset is the ideal planting time, requiring soil preparation with a hole twice the size of the root ball. After firm planting and deep watering, regular irrigation especially during dry spells is necessary. Nutrient-rich compost or organic manure supports optimal growth. Pruning is beneficial for maintaining shape and enhancing fruit yield (Taitano *et al.*, 2023) [44].

India plays a significant role in global star gooseberry production, contributing 10.9% of the world's output, with a total yield of 58.7 million tonnes over 5.5 million hectares. Key cultivating states include Andhra Pradesh, Karnataka, and Maharashtra. The crop's adaptability to low-fertility or degraded lands underlines its economic viability and potential for expansion in Indian agriculture (Hemalatha, 2010) [16].

Botanically, the star gooseberry is a deciduous shrub or small tree reaching up to 10 meters in height. It features phyllanthoid branching, grey bark with prominent lenticels, and compound leaves 20-40 cm long with alternate, ovate to ovate-lanceolate leaflets. The upper leaf surface is smooth and green, while the underside is bluish-green. Small reddish-pink flowers develop in cymule clusters on leafless nodes of mature branches. Each leaflet pair has two pointed stipules at the base a distinct feature of the species (Tan *et al.*, 2020).

The fruit is oblate, 1-2.5 cm in diameter, and grows in dense clusters on the trunk and main branches. It turns from greenish-yellow to creamy-white upon ripening and possesses a waxy, crisp, juicy, and highly acidic flesh. Fruits are pendulous, forming in clusters of 30-60 per inflorescence, maturing in 40-45 days. Despite this productivity, significant pre-harvest fruit drop (50-75%) is common, reducing overall yield to 2-3 kg per plant per flush (Rai *et al.*, 2005 [33]; Kishore *et al.*, 2007) [22].

Physical attributes include an average fruit weight of 3.15 g, seed weight of 0.16 g, fruit length of 1.73 cm, and diameter of 1.47 cm. The seed measures 0.66 cm in length and 0.98 cm in diameter. The fruit exhibits a volume of 3 ml and a specific gravity of 1.05. The edible portion accounts for 94.92% of the total fruit, with an edible to non-edible portion ratio of 18.68 (Layek *et al.*, 2023) [23].

While *P. acidus* is well-suited to tropical lowlands and mid-altitudes, it remains underutilized and is often treated as agricultural waste, leading to revenue loss (Ramalingam *et al.*, 2021) [34]. Breeding programs aim to improve the species by developing miniature trees that bear early, produce high yields of large, high-quality, seedless fruits with longer shelf life and reduced sourness (Rymbai *et al.*, 2015) [37].

Nutritional Properties of *Phyllanthus acidus*

Phytochemicals in plants are broadly categorized as primary and secondary metabolites based on their metabolic roles. Primary constituents such as sugars, amino acids, proteins, purines, pyrimidines, and chlorophyll are essential for fundamental physiological processes. In contrast, secondary metabolites though not vital for basic survival play important ecological and therapeutic roles. These include alkaloids, terpenes, flavonoids, lignans, plant steroids, curcumins, saponins, phenolics, and glucosides (Hahn, 1998) [15].

The fruits of *Phyllanthus acidus* (star gooseberry) are rich in moisture and offer a valuable nutritional profile. They are an excellent source of sugars, organic acids, phenolic compounds, and important minerals such as iron, calcium, manganese, potassium, and zinc. In addition to high water content, the fruit contains glucose, fructose, ascorbic acid, carotenoids, and several macro- and micronutrients, including calcium, magnesium, and iron supporting its potential as a functional dietary component (Durham *et al.*, 2002 [10]; Jahan *et al.*, 2011 [19]; Siddiqui *et al.*, 2022) [40].

Primary metabolites are integral to growth, energy production, and cell development. In contrast, secondary metabolites though not directly linked to growth or reproduction serve ecological functions and provide pharmacological benefits (Sung *et al.*, 2015) [43]. While primary metabolites address human nutritional requirements, secondary metabolites often offer therapeutic effects.

Primary Metabolites

Phyllanthus acidus is a rich source of both essential and non-essential amino acids. Isoleucine (49.187 mg/g) and valine (40.613 mg/g) are the most abundant essential amino acids, accompanied by arginine, histidine, leucine, lysine, methionine, phenylalanine, threonine, and tryptophan. Among non-essential amino acids, proline (64.242 mg/g), glutamine (60.744 mg/g), glycine (57.608 mg/g), and aspartate (17.905 mg/g) are present in considerable amounts, highlighting the fruit's potential in nutritional supplementation (Jose and Rajani, 2017).

According to Mahapatra *et al*. (2012) [25], 100 g of the edible portion of *P. acidus* contains 91.9 g water, 28 kcal energy, 0.155 g protein, 0.52 g fat, 6.4 g carbohydrates, and 0.8 g dietary fiber. It also contains significant mineral content: calcium (5 mg), iron (2.43 mg), phosphorus (23 mg), potassium (223.44 mg), calcium (163.22 mg), sodium (17.5 mg), zinc (1.63 mg), manganese (1.31 mg), and copper (0.2 mg). Vitamin content includes carotene (0.019 mg), ascorbic acid (8 mg), thiamine (0.01 mg), riboflavin (0.05 mg), and niacin (0.292 mg).

P. acidus is notably high in vitamin C, with an ascorbic acid content of approximately 36.7 mg per 100 g of fruit. A mere 8.75 mg of natural vitamin C from star gooseberry is equivalent in potency to 100 mg of synthetic vitamin C, making it a highly efficient source of the nutrient (Tan *et al.*, 2020). Additionally, its use as a feed additive has been explored to improve immunity, enhance growth, and reduce feeding costs through improved efficiency.

Biochemically, the fruit contains 5.75 °Brix of total soluble solids, 2.5% total sugars (1.29% reducing and 1.21% non-reducing sugars), indicating its nutritional value (Layek *et al.*, 2023) [23].

Secondary Metabolites

Secondary metabolites in plants are responsible for a wide range of health-promoting effects. These compounds are influenced by varietal, geographical, seasonal, and agronomic factors (Atal *et al.,* 1975; Mahan and Escott-Stump, 2004) [24].

Ultra-high performance liquid chromatography (UHPLC) identified several phenolic compounds in *P. acidus* fruit extract, including gallic acid, myricetin, quercetin, kaempferol, and dihydroquercetin. These contribute to the extract's potent α-glucosidase inhibitory activity, placing it among the most bioactive tropical fruits tested in Malaysia (Sulaiman and Ooi, 2014) [42].

The antioxidant activity of *P. acidus* is attributed to its abundance of terpenoids, phenols, and flavonoids such as gallic acid, rutin, quercetin, and myricetin. These compounds help neutralize free radicals and improve antioxidant enzyme function, thus reducing lipid peroxidation (Siddiqui *et al.,* 2022) [40].

Shilali *et al.* (2014) [39] reported that ethanolic extracts of the bark exhibited up to 90% ABTS radical scavenging activity at 50 µg/mL, with methanolic extracts revealing the presence of quercetin, gallic acid, rutin, myricetin, luteolin, p-coumaric acid, and hydroxybenzoic acid.

Further phytochemical investigations have revealed the presence of various terpenoids including norbisabolane sesquiterpenoids (phyllanthusol, phyllanthacidosis), diterpenoids (phyllane, spruceanol), and cleistanthane-type diterpenes (phyllaciduloids). These compounds are largely isolated from the bark and root tissues (Tan *et al.,* 2020).

Several sesquiterpenoids contain a carboxylic acid group linked to sugar units. Among seven diterpenoids identified, five belong to the cleistanthane class. Recent discoveries include phyllaciduloids, acidoflavanone, acidoauronol, 5-O-methylacidoauronol, acidoaurone, phyacidusin, and phyllanthacidoid (Zheng *et al.,* 2018 [50]; Duong *et al.,* 2018 [9]; Gu *et al.,* 2019) [13].

A total of 14 flavonoids have been isolated from *P. acidus*. Flavonol glycosides with sugar groups attached at the C3 position were found in the leaves, while sulfonic acid-substituted flavonoids were isolated from the roots. In addition, a nucleoside and hypo gallic acid were reported by Sousa *et al.* (2007) [41]. Furthermore, 77 volatile compounds have been identified in ripe fruits through NBS and NIST mass spectral libraries (Tan *et al.,* 2020).

Health Benefits of Star Gooseberry (*Phyllanthus acidus*)

For centuries, medicinal herbs have played a pivotal role in traditional pharmacology. In Thailand alone, over 500 herb-based formulations are used for treating conditions such as cancer, diabetes, and cardiovascular diseases. These herbal preparations are also incorporated into dietary supplements and athletic medicine, known for their diuretic, anti-inflammatory, anti-asthmatic, and antihypertensive properties (Panthong *et al.,* 1986) [30]. Both developed and developing nations continue to depend on plant-based traditional medical systems (Nisar *et al.,* 2018) [29].

Phyllanthus acidus has been traditionally employed in managing various ailments, including inflammation, rheumatism, asthma, bronchitis, liver disorders, diabetes, and hypertension (Tan *et al.,* 2020). The fruit extracts are recognized for their hypoglycemic, analgesic, antidiarrheal, and anesthetic effects (Afrin *et al.,* 2016) [1].

Antioxidant Activity

Although elemental oxygen is crucial for aerobic life, it can lead to the production of reactive oxygen species (ROS) such as peroxides and hydroxyl radicals, which induce oxidative stress and cellular damage (Andrianto *et al.,* 2017) [3]. Antioxidants counteract these effects by neutralizing free radicals. Extracts from *P. acidus* fruits and leaves have demonstrated significant antioxidant activity, potentially contributing to cardiovascular protection (Nisar *et al.,* 2018) [29].

According to Wu *et al.* (2011) [48], antioxidants neutralize hydroperoxide, peroxide, and lipid peroxyl radicals, thereby inhibiting degenerative processes. The methanolic fruit extract of *P. acidus* exhibited up to 90% ABTS radical scavenging activity at 50 µg/mL, attributed to phenolic compounds like gallic acid, rutin, quercetin, myricetin, luteolin, coumaric acid, and hydroxybenzoic acid (Siddiqui *et al.,* 2022 [40]; Tan *et al.,* 2020).

Loan *et al.* (2017), reported that pectinase-aided juice extraction significantly enhanced antioxidant properties. Under optimized conditions (19 PGU/100 g dry pulp for 67 minutes), antioxidant activity peaked at 5595 ± 6 µmol Trolox equivalents per 100 g dry weight, with phenolic and ascorbic acid levels increasing by 157% and 21%, respectively.

Andrianto *et al.* (2017) [2], evaluated extracts from various solvents using DPPH assays. Although the water extract had the lowest yield, it demonstrated the strongest antioxidant activity (IC_{50} = 26.06 µg/mL) and the most potent cytotoxic effect (LC_{50} = 473.26 µg/mL). Foyzun *et al.* (2016) [11, 12] found that both pulp and seed extracts displayed strong antioxidant activities, with LC_{50} values of 5.96 and 6.79 µg/mL, respectively.

Additionally, chloroform and methanol extracts exhibited higher antioxidant activity compared to petroleum ether extracts, with activity increasing proportionally with concentration (Habib *et al.,* 2011) [14].

Anti-inflammatory Activity

Traditionally, *Phyllanthus acidus* has been utilized to treat inflammatory conditions. Scientific studies confirm the anti-inflammatory effects of its leaves and fruits. Green-synthesized silver nanoparticles (AgNPs) using fruit extract showed notable nitric oxide and superoxide radical scavenging activity, along with reduced IL-1β expression, without affecting macrophage viability (Manikandan *et al.,* 2017) [26].

Chakraborty *et al.* (2012) [6] highlighted the presence of antioxidant, analgesic, and anti-inflammatory agents in *P. acidus*, suggesting potential therapeutic applications. Flavonoids and phenolic compounds are believed to mediate these effects (Hossain *et al.,* 2016) [17].

The plant has also been traditionally used in conditions such as bronchial catarrh, asthma, skin rashes, and psoriasis (Tan *et al.,* 2020). The flavonoids kaempferol and quercetin, as well as tannins and lignans in *P. acidus*, exert anti-inflammatory effects by inhibiting cyclooxygenase and lipoxygenase enzymes, which mediate prostaglandin and leukotriene biosynthesis (Chakraborty *et al.,* 2015) [6].

Pugazhendhi *et al.* (2022) [31], evaluated the anti-arthritic potential of alcoholic fruit extracts in rats, finding significant reduction in paw edema. Siddiqui et al. (2022) [40]

noted that the extract suppressed key inflammatory mediators, including NO and IL-1β, and protected against oxidative stress under hyperglycemic conditions.

Antidiabetic Activity

Diabetes mellitus, a chronic metabolic disorder characterized by elevated blood glucose, poses a major public health concern globally. In developing countries like Bangladesh, its prevalence has surged significantly (Marles and Farnsworth, 1995) [27]. Plant-based therapies continue to play an essential role in managing diabetes.

Extracts from various parts of *P. acidus* have shown significant hypoglycemic and hypolipidemic effects. Talubmook and Buddhakala, (2013) [45] reported that leaf extracts induced hyperinsulinemia and improved lipid profiles. Afrin *et al.* (2016) [1] demonstrated that methanolic fruit pulp extract significantly reduced glucose levels and showed antidiarrheal activity.

Chigurupati (2020) [7] suggested that ethanolic seed extract may serve as a nutraceutical alternative for managing postprandial hyperglycemia and oxidative stress. Histopathological evaluations confirmed β-cell regeneration and normalization of biochemical markers (Shilali *et al.,* 2014) [39].

Chaimum-aom *et al.* (2017) [5] observed β-cell regeneration and enhanced insulin production in streptozotocin induced diabetic rats. Although a single 250 mg/kg dose of leaf extract did not lower blood glucose in normal rats, the extract was deemed non-toxic at 2,000 mg/kg.

Unander *et al.* (1990) [47] noted that *P. acidus* and *P. emblica* are rich in vitamin C and are traditionally used to support vision, memory, and diabetes management. According to Siddiqui *et al.* (2022) [40], the antidiabetic mechanisms involve α-glucosidase inhibition, suppression of PPAR-γ, and increased insulin secretion.

Yanadaiah *et al.* (2012) [49] reported dose-dependent glucose reduction following ethanolic extract administration over 21 days in diabetic rats. Flavonoids, tannins, and phytosterols likely contributed to these effects via insulin-mediated pathways and β-cell regeneration.

Sulaiman and Ooi (2014) [42] found that 50% ethanol extracts from leaves and fruits displayed the highest α-glucosidase inhibitory activity with the lowest IC_{50} values. This correlates with earlier findings demonstrating strong inhibitory activity in *P. acidus* fruit juice.

Antimicrobial Activity

The antimicrobial efficacy of *Phyllanthus acidus* has been demonstrated against a wide range of bacterial and fungal pathogens. Methanolic fruit extracts were effective against *Bacillus cereus*, while seed extracts inhibited *Shigella dysenteriae*, *Vibrio cholerae*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Staphylococcus aureus*, and *Escherichia coli* (Foyzun *et al.*, 2016) [11, 12].

Aqueous leaf extract exhibited activity against *E. coli*, *S. aureus*, and *Candida albicans* (Jagessar *et al.,* 2008) [18]. Sankannavar and Patil (2012) [38] confirmed its moderate efficacy against *S. typhi*, *V. cholerae*, and *P. aeruginosa*.

Tan *et al.* (2020) reported that acetone fruit extracts inhibited *E. coli* and *P. aeruginosa* most effectively, with inhibition zones of 19 and 20 mm, respectively. Biswas et al. (2011) [4] observed that ethanolic bark extract (500 μg/mL) produced a 32 mm inhibition zone against *S. typhi* and inhibited *E. coli* and *V. cholerae* as well. The presence of glycosides, tannins, and resins may contribute to these effects, particularly against Gram-negative bacteria.

Conclusion

Phyllanthus acidus (star gooseberry) emerges as a promising underutilized fruit with considerable nutritional and therapeutic potential. This review consolidates available data on its production scenario, nutrient composition, and multifaceted health benefits. The fruit is a rich source of vitamin C, phenolic compounds, flavonoids, and dietary fiber, all of which contribute to its strong antioxidant profile. Scientific studies substantiate its pharmacological properties, including anti-inflammatory, antidiabetic, antimicrobial, and antioxidant activities. These bioactivities are largely attributed to its phytochemical constituents such as quercetin, gallic acid, and kaempferol. Despite its traditional use in various medicinal systems, *P. acidus* remains underexplored in terms of commercial utilization and scientific validation. Future research focusing on clinical studies, value addition, and formulation of functional foods could significantly enhance its application in the nutraceutical and pharmaceutical sectors. Promoting its cultivation and processing may not only contribute to health and nutrition but also offer new economic opportunities, particularly in tropical and subtropical regions.

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